

Guidelines

Guidelines for the peri-operative management of people with cardiac implantable electronic devices

Guidelines from the British Heart Rhythm Society

H. Thomas,¹  C. Plummer,² I. J. Wright,³ P. Foley⁴ and A. J. Turley⁵

1 Consultant, Department of Cardiology, Northumbria Healthcare NHS Foundation Trust, Northumberland, UK

2 Consultant, Department of Cardiology, Newcastle upon Tyne NHS Foundation Trust, Newcastle upon Tyne, UK

3 Physiologist, Department of Cardiology, Imperial College Healthcare NHS Foundation Trust, London, UK

4 Consultant, Department of Cardiology, Great Western Hospitals NHS Foundation Trust, Swindon, UK

5 Consultant, Department of Cardiology, South Tees NHS Foundation Trust, Middlesbrough, UK

Summary

This document provides practical guidance for the management of people with cardiac implantable electronic devices who are undergoing surgical intervention. Increasing numbers of people have cardiac device implants including pacemakers, implantable defibrillators and cardiac resynchronisation devices. During surgical procedures, exposure to electromagnetic interference may lead to inappropriate device function including withholding of pacing function or shock therapies. The guideline summarises key aspects of pre-operative assessment protocols to ensure that all people have their device clearly identified and have had appropriate device follow-up pre-operatively. It outlines general measures which can minimise the risk of potentially problematic electromagnetic interference in the surgical environment. It also includes detailed guidance according to the type of device, whether individuals are dependent on the pacing function of the device and the nature of the procedure they are undergoing. People identified as being at significant risk of harmful procedure-related inappropriate device function may require temporary alteration to the device programming. This may be carried out by a trained cardiac physiologist using a device programmer or, in some cases, can be achieved by clinical magnet application. Guidance on the safe use of magnets and emergency situations is included. Common diagnostic procedures and dental interventions are covered. The guidance aims to provide specific and pragmatic advice which can be applied to provide safe and streamlined care for people with cardiac implantable devices.

Correspondence to: H. Thomas

Email: honey.thomas@nhct.nhs.uk

Accepted: 16 March 2022

Keywords: electromagnetic interference; implantable cardioverter defibrillator; pacemaker; peri-operative management

Re-use of this article is permitted in accordance with the Creative Commons Deed, Attribution 2.5, which does not permit commercial exploitation.

What other guidelines are available on this topic?

There are no other specific UK guidelines on this topic and this document is an updated version of guidance published in 2016 [1]. The most recent other UK publication is an alert in 2006 from the Medicines and Healthcare products Regulatory Agency (MHRA), which is now outdated and very limited in content [2]. The European Society of Cardiology guidelines on non-cardiac surgery refer briefly to people with cardiac implantable electronic devices (CIEDs) but in very little detail [3]. The American Heart Rhythm Society and American Society of Anesthesiologists consensus statement on the peri-operative management of implantable defibrillators, pacemakers and arrhythmia monitors offers some guidance [4]. An update from the American Society of Anesthesiologists has also given some helpful summary advice [5].

Why were these guidelines developed?

This document is intended to provide practical guidance for people with CIEDs undergoing surgical intervention, expanding on the British Heart Rhythm Society guidance first published in 2016 [1]. This guidance also includes advice regarding common diagnostic procedures and dental interventions. It is recognised that there are limited trial data to guide clinicians in some areas and most evidence is in the form of expert opinion. This document will be reviewed by the British Heart Rhythm Society on a biannual basis.

Key recommendations

- 1 In people with cardiac implantable electronic devices, electromagnetic interference in the surgical environment may lead to an inappropriate pacemaker function or implantable cardiac defibrillator shocks.
- 2 Identification of these devices at pre-operative assessment is important to allow appropriate precautions to be taken.
- 3 Pre-operative assessment teams should ensure the cardiac implantable electronic device has been under regular follow-up, and contact their usual cardiology team. Remote device follow-up should be regarded as equivalent to in-person follow-up in patients with normal functioning devices.
- 4 General precautions should be followed when any person with a cardiac implantable electronic device has a procedure which may involve electromagnetic interference including: monitoring; diathermy plate positioning; use of short bursts of diathermy; and availability of appropriate emergency equipment.

- 5 Specific procedures will require differing levels of device reprogramming and this may vary according to whether the person is dependent on the pacemaker function of their device.
- 6 Surgery below the umbilicus may not require implantable cardioverter defibrillator deactivation.
- 7 The guidance recognises that temporary magnet deactivation or programmer deactivation of therapies are both acceptable methods of deactivating defibrillators.
- 8 Safe magnet use requires an awareness of importance of positioning and securing the correct clinical magnet.
- 9 Responsibility for patients remains with the clinical team responsible for the episode of care (rather than cardiac physiologists and cardiology teams). The clinical team is responsible for ensuring the reactivation of devices which have been deactivated by programming
- 10 Dental procedures are included and the use of ultrasound scalers is not anticipated to cause problems with cardiac devices.

Introduction

The use of CIEDs for rhythm management includes: pacemakers for the management of bradycardia; implantable cardioverter defibrillators (ICDs) for the treatment of life-threatening ventricular tachycardia; biventricular or resynchronisation pacemakers (CRT-P) and cardiac resynchronisation therapy defibrillators (ICRT-D) for the treatment of heart failure; and implantable loop recorders (ILRs) or insertable cardiac monitors (ICMs) for monitoring cardiac arrhythmias. These devices generally fall into three categories: implantable loop recorders/cardiac sensors which allow for targeted ECG monitoring; cardiac pacemakers (single-lead, dual-lead, biventricular or leadless); and ICDs (single-lead, dual-lead or biventricular).

The presence of these devices may present a problem when procedures are carried out in which the person may be exposed to electromagnetic interference (EMI) leading to inappropriate device function. Precautions therefore need to be considered before these procedures for the safe management of people with CIEDs.

Both pacemakers and ICDs have been designed with a high degree of tolerance to electrical and magnetic interference fields, and special filtering components have been incorporated to minimise the effects of these. A problem may arise, however, if the energy level of a nearby field is very high, or has a frequency component that is close to that generated by the heart. This may have a variety of effects on the function of the CIED including: inhibition of pacing; induction of fixed-rate pacing; inappropriate rapid

pacing; software reset; or triggering of shocks in an ICD. Most types of EMI interfere only transiently with device function, and when the interference ceases the device returns to normal. Only very powerful fields are likely to have any permanent effects on device or lead function (e.g. gamma radiation or very strong magnetic fields such as MRI scanners). Potential sources of EMI in the surgical setting include: intra-operative MRI; diathermy/electrosurgery; nerve stimulators; transcutaneous electrical nerve stimulation (TENS) machines; radiofrequency scanners for surgical instrument detection; magnetic guidance systems; and radiofrequency ablation devices.

Pacemaker sensing of EMI may inhibit appropriate pacing as the device wrongly interprets EMI as intrinsic cardiac rhythm. This is most concerning in people who are pacing-dependent and do not have any underlying rhythm. In addition, where a CIED uses an impedance-based rate responsive pacing function (e.g. minute ventilation sensor), interference from diathermy or manipulation of the device can be sensed by the implant, resulting in an inappropriate high-rate pacing, although this is unlikely to lead to clinical harm.

Implantable cardioverter defibrillators are designed to treat arrhythmias such as ventricular tachycardia or ventricular fibrillation; hence there is the possibility that the EMI may be misinterpreted as a ventricular arrhythmia causing an inappropriate initiation of anti-tachycardia therapy or delivery of shocks. Inappropriate shocks from an ICD are associated with increased mortality, and it is vital these are avoided, even if an anaesthetised person would be unaware of them [6]. In addition, unanticipated movement associated with shock delivery may be harmful during surgery.

Manufacturers of implantable pacemakers and ICDs either contraindicate the use of surgical diathermy/electrocautery, or give strong warnings against its use, especially the monopolar mode. However, where surgical diathermy/electrocautery is essential, if it is used at a site remote from the implanted device and the electrodes are positioned appropriately, then there is a low risk of any effect on the device which may lead to an inappropriate function. The use of bipolar surgical diathermy/electrocautery should be considered (in preference to monopolar) wherever possible, although there are still small risks associated with this.

Implantable loop recorders and insertable cardiac monitors record cardiac signals and there is no risk to the patient with any surgical procedure. The device may interpret EMI as a rapid heart rhythm and record an episode of 'tachycardia' but this will be apparent when the device is interrogated. No additional precautions are needed for a

patient with these devices. However, it may be useful to interrogate the device electively before, and clear the diagnostic memory after, the procedure in case the memory is filled with episodes of detected EMI.

Pacing dependency

People receive CIED therapy for a number of different reasons (Box 1). The presence of pacing stimulation artefacts on an ECG does not mean that the person is pacemaker-dependent, that is, that their heart rhythm always requires a stimulus from the pacemaker to avoid a potentially harmful bradycardia.

The prevalence of pacemaker-dependency in people with CIEDs is determined by the definition used. The Heart Rhythm Society defines pacemaker-dependency as no intrinsic rhythm $> 40 \text{ beats.min}^{-1}$ or haemodynamic instability with the intrinsic rhythm [7]. In clinical practice, a person is pacing dependent when they have an inadequate or absent intrinsic heart rhythm, which becomes symptomatic if there is a (sudden) failure of CIED pacing function. A frequently used definition is the absence of any spontaneous ventricular activity or presence of low-rate, clinically not tolerated, spontaneous activity when the CIED is transiently programmed in VVI $30\text{--}40 \text{ beats.min}^{-1}$ [8]. The majority of people are not pacing-dependent based on this definition and, as such, if their device was temporarily turned off or damaged, they would not come to serious harm or death from sudden CIED failure [9].

People who are pacing-dependent are at greater risk from EMI inhibition of their pacing function and, if prolonged diathermy is anticipated in proximity to the device, reprogramming to a fixed-rate pacing mode should be considered.

Planned surgical procedures in people with CIEDs

Patient screening

Since the majority of surgical procedures are planned in advance, people with these devices should be identified through pre-operative screening. Although the pre-operative process may request patients to declare if they have a pacemaker/ICD, this should be independently verified and noted in the records. People with these devices are usually provided with a registration card recording details of the device and its manufacturer. An example flow chart is available in online Supporting Information Appendix S2, which can be used to identify lines of responsibility and communication, particularly to cardiac physiologists, when such patients are identified before elective surgery.

Box 1 Cardiac implantable electronic devices with pacemaker functionality.

Permanent pacemaker	Implanted to treat bradycardia. These devices are programmed to promote intrinsic cardiac activity and as such pace only when the heart rate falls below a pre-set level (typically 60 beats.min ⁻¹)
Implantable cardioverter defibrillators (ICDs)	Implanted to treat people who have suffered, or are at high risk of suffering, from a ventricular arrhythmia. These people typically do not have an indication for a permanent pacemaker and the device may be programmed to pace the heart only if the heart rate is < 40 beats.min ⁻¹ . A small proportion of ICDs are S-ICDs (subcutaneous) and these are typically implanted in the axilla, do not have leads within the heart and are unable to offer conventional pacing support.
Cardiac resynchronisation therapy	Implanted to treat people with heart failure. These devices work by co-ordinating ventricular contraction and, as such, are programmed to pace the heart continuously. The WiSE-CRT system (EBR Systems, Sunnyvale, CA, USA) uses an ultrasound transmitter with a separate battery unit, both of which are implanted in the chest wall to stimulate a 'seed' (small ultrasound-sensitive electrode) situated in the left ventricle. The manufacturer advises specific precautions regarding this device. Currently, this technique has been used in a small number of people and the implanting centre should be contacted before any procedures for advice. See online Supporting Information Appendix S1 for more detailed information.
Leadless pacemaker	Leadless pacing systems, typically the Micra single-chamber transcatheter pacing system (Medtronic, Minneapolis, MN, USA), may be implanted in a small number of people. These devices are small and implanted directly into the cardiac muscle. They typically pace the heart when the heart rate drops in a similar way to a conventional system. Advice regarding potential EMI effects is similar to conventional devices with leads.

Recording pacemaker/ICD details

When a pacemaker/ICD is identified, it should be clearly recorded in the clinical notes by the surgical/procedural assessment staff and marked for the attention of key clinical staff. Before surgery, the anaesthetist and surgeon/operator involved should be aware of the implications of the patient having a CIED.

Where possible, the following key information should be noted for future reference (and will be available via the patient's usual hospital pacing clinic): type of device and manufacturer; implanting hospital; follow-up hospital; date of last follow-up; if the device is at or approaching battery depletion; if the device is part of a clinical investigation, where restrictions may apply; and device location. Device location is relevant when considering the implications of the procedure as CIEDs are usually implanted in the left or right pre-pectoral region; however, some devices may be located in the left lateral chest wall (S-ICDs) and, very rarely, the abdomen.

The person's follow-up clinic will be able to confirm the correct functioning of the pacemaker/ICD and check the condition of the battery and leads before surgery. Additional pre-operative checks are not required providing regular follow-up is not overdue. The clinic undertaking follow-up of the device will be able to advise if the person is pacing-dependent and if adjustments to sensing/pacing parameters are required (the majority of devices will not require changes before or after surgery). If ICD deactivation

is necessary, local follow-up centres should have a standard operating procedure which will detail the option of either temporary magnet deactivation or reprogramming the device to prevent shock therapy.

Many devices are now under remote follow-up, and device interrogation may be possible without the need for the person to attend the clinic face-to-face. Remote threshold checks are equivalent to in-clinic tests; a person with stable lead parameters does not need an additional in-person check before surgery if the parameters are satisfactory on remote monitoring. If reprogramming is required, it is not possible to do this via the remote systems, and must be done face-to-face.

Considering additional peri-procedural support

At the time of the procedure, the following should be considered when surgical diathermy/electrocautery or other devices with potential for EMI are to be used on a person with a CIED. Electrocardiogram monitoring should be started from the outset of the procedure. Some monitors may give inaccurate readings of paced beats, so if in doubt check the person's pulse and/or use pulse oximetry. External defibrillation equipment, external temporary pacing and cardiopulmonary resuscitation equipment should be available. In people who have their ICD deactivated and where access to the anterior chest wall will interfere with surgery (or the sterile field), consider connecting the person to an external defibrillator using

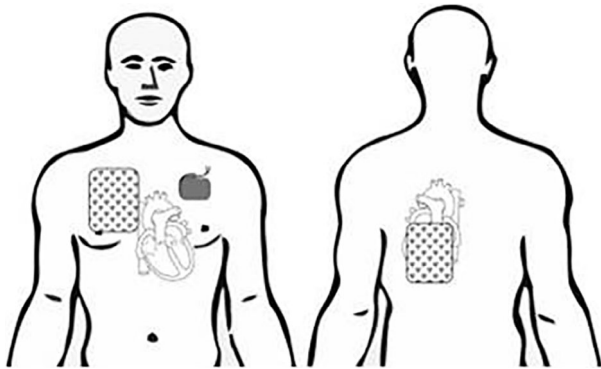


Figure 1 Recommended positioning of defibrillation pads in people with implantable devices. Reproduced with permission from [24].

remote pads. Defibrillator pads should be positioned as far away from a CIED as possible (Fig. 1), and never directly over the device (pulse generator) itself. Where diathermy/electrocautery is unavoidable, limit its use to short bursts at the lowest feasible energy level and use bipolar diathermy if possible. Surgical teams should ensure that the return electrode is anatomically positioned so that the current pathway between the diathermy electrode and return electrode is as far away from the pacemaker/defibrillator (and leads) as possible. Underbody electrodes are not recommended [10]. If detectable pacemaker inhibition occurs, or there is evidence of ICD therapy being delivered, the surgeon should be informed immediately and diathermy either used intermittently for short bursts or discontinued. Magnet application can be considered if this is not possible (see below). If device programming has been altered for a surgical procedure, people need to have ECG monitoring until their device parameters have been restored to pre-operative settings and/or the ICD is reactivated. This should be done as soon as practical and ideally in the post-anaesthesia care unit. Responsibility for arranging this remains with the treating surgical team.

Guidance for CIED programming/interrogation for specific procedures

Table 1 shows a suggested guide for required actions in different clinical situations. There is relatively little evidence for specific types of surgery [7, 11, 12]. These guidelines represent an attempt to provide practical guidance for common situations based on a consensus of expert opinion using the limited available data and device manufacturers' information. There is evidence that EMI is more likely to affect device function if it is used near the pulse generator or

leads. Typically, this occurs in surgery performed superior to the umbilicus, but is not likely during procedures below the umbilicus [10, 13–17]. Therefore, in procedures below the umbilicus, it is reasonable not to carry out ICD deactivation/pacemaker reprogramming. However, a magnet should be immediately available for emergency use. Postoperative checks are not usually required unless programming has been altered.

If ICDs are disabled for surgery, it is important to ensure they are re-enabled after surgery. Failure to re-enable tachycardia therapies after surgery will leave the person without protection from ventricular arrhythmias which could result in their death. If ICD function is to be suspended for surgery, surgical departments must have procedures in place to ensure the device is returned to normal operation as soon as practicable after procedures, and that checks are in place to ensure people will not be discharged to an unmonitored environment, or even home, without this having taken place. Responsibility for arranging this remains with the treating surgical team.

Suspension of ICD treatment can be achieved by deactivation of the device by a member of the cardiac team using a programmer or temporary application of a clinical magnet. There are practical advantages and disadvantages to these approaches. Deactivation is a more definite approach which ensures guaranteed suspension of therapies or programming changes. However, it requires input from the cardiac team before and after surgery (which can be challenging logistically), and while the device is awaiting reactivation, it will not treat potentially serious arrhythmias. Magnet deactivation is an alternative and is recommended in emergency situations or where programmer deactivation is not feasible. Magnet application is available where cardiac physiologists are not on site, and reduces the risk that patients fail to have therapies turned back on after surgery. A potential disadvantage of magnet deactivation is that the magnet may be positioned inappropriately or move unintentionally away from the device (this may not be easily apparent when the magnet is placed). In this case, anti-tachycardia therapies may be delivered inappropriately. Centres should have a standard operating procedure in place to guide which approach for device deactivation is used and how this is accessed. Device deactivation is recommended for exceptionally delicate surgery procedures such as neurosurgery where any movement from an ICD shock could be detrimental, and these should be regarded as exceptional cases if they lie outside the general institutional protocol.

Table 1 Peri-operative management of people with cardiac implantable electronic devices.

	Pacemaker		Implantable defibrillator	
	Pacing-dependent	Not dependent	Pacing-dependent	Not dependent
Surgery above umbilicus	Consider reprogramming to fixed rate if prolonged diathermy anticipated	Monitor during surgery to ensure no inhibition of pacemaker. No reprogramming	Deactivation of ICD. Consider reprogramming to fixed-rate pacing or Magnet application as alternative only if prolonged diathermy not anticipated.	Deactivation of ICD or Magnet application
Surgery below umbilicus	Monitor during surgery to ensure no inhibition of pacemaker. No reprogramming. Clinical magnet should be available	Monitor during surgery to ensure no inhibition of pacemaker. No reprogramming	Monitor during surgery to ensure no inhibition of pacemaker or inappropriate therapies. Reasonable not to deactivate ICD. Clinical magnet should be available	
Cardiac surgery	Reprogramming likely to be required		Deactivation of ICD ± reprogramming during surgery	
Eye surgery	As for surgery above the umbilicus if monopolar diathermy is used			
Endoscopy	Consider reprogramming to fixed rate if prolonged diathermy or argon beam anticipated	Monitor during procedure to ensure no inhibition of pacemaker. No reprogramming	Deactivation of ICD. Consider reprogramming to fixed-rate pacing if diathermy/argon anticipated or Magnet application as alternative only if prolonged diathermy/argon not anticipated.	Deactivation of ICD if diathermy/argon anticipated or Magnet application
Dental	No action required unless requirement for diathermy use			
Lithotripsy	Interrogate device within 1 month after treatment		Deactivation of ICD during therapy session or Magnet application	
	Avoid focussing beam near the pulse generator. If lithotripsy triggers on R-wave, consider disabling atrial pacing during treatment			
Electroconvulsive therapy	Interrogate device within 1 month after treatment		Deactivation of ICD during procedure or Magnet application	
Nerve conduction studies* [16, 17]	Consider reprogramming to fixed-rate pacing	Monitor during procedure to ensure no inhibition of pacemaker. No reprogramming	Deactivation of ICD and consider reprogramming to fixed-rate pacing or Magnet application as alternative only if prolonged stimulation not anticipated	Deactivation of ICD. or Magnet application

*If repetitive, prolonged and close to the device. ICD, implantable cardiac defibrillator.

Surgical magnetic drapes

Caution should be exercised when using magnetic drapes to hold surgical equipment as these may cause magnet effects in the CIED [18]. Placement of magnetic drapes on the thorax should be avoided. The use of bottom-isolated magnetic drapes may reduce the risk of interaction with the implanted device.

Magnetic anchoring and guidance systems

Magnetic anchoring and guidance systems are used in laparoscopic and endoscopic surgical procedures to provide traction and control in the surgical environment using an external magnet to manipulate an internally positioned instrument [19, 20]. These systems require the use of a powerful external magnet. There are no direct data

of the effect of these systems on CIEDs, but it is likely that device therapy would be affected by the magnet itself [21] in addition to potential EMI. The system manufacturers state that the presence of a CIED is a contraindication to their use. In selected patients, it may be possible to programme a device to mitigate some of this risk, but in general these magnetic systems are not recommended in people with CIEDs.

Capsule endoscopy

It has been suggested that there may be a theoretical risk of EMI with capsule endoscopy, but European guidance and a review of the available literature show no evidence of any clinical risk [22, 23]. Image quality may be affected rarely.

Dental procedures and ultrasonic cleaning

There has been conflicting evidence regarding potential interactions between CIEDs and a variety of dental devices. There is no clear and widely accepted national or international guidance. Reports have been largely based on in-vitro studies of people with older generation cardiac devices and often older generation dental equipment. Newer cardiac devices are designed to minimise the effects of EMI. The latest evidence would suggest that at a distance of at least 15 cm, interference from ultrasonic scalers, apex locators, pulp testers and drills is not likely to pose any clinical risk to people with CIEDs.

Operators should avoid draping any leads or cords across the patient. In addition, using the devices for short bursts minimises any potential risk. The manufacturers of the most widely used CIEDs in the UK support this conclusion in their literature. People with implantable devices should be carefully observed during dental procedures. If EMI was to cause inhibition of the pacemaker causing any symptoms or if the device was to beep or vibrate, prompt cessation of use of the dental tool and moving it away from the patient will allow normal device function to resume. Therefore, if use of the dental equipment would have appreciable benefits for the person's dental outcome, then this is likely to outweigh any small theoretical risks to their cardiac device.

Emergency procedures

Wherever possible, the steps outlined above should be followed whenever emergency surgery is required. Temporary pacing in accordance with advanced life support guidance should be available.

Cardiac arrest

In the case of cardiac arrest, resuscitation should be carried out in the same way as if there were no device. This is

regardless of the programmed functionality of the device at the time of the arrest. There is no significant risk to someone performing cardiopulmonary resuscitation or touching the person if a shock is delivered by an ICD. If an external shock is needed in a person with an implantable device, defibrillation pads should be positioned as far away as possible from the device, and ideally in the antero-posterior position (Fig. 1). Energy from external defibrillation can damage an implantable device, so if the resuscitation attempt is successful then the device should be interrogated afterwards to confirm its function.

Magnets and CIEDs

Implantable devices respond to placement of a magnet positioned immediately over them in a variety of ways. The response to the presence of a magnet in both pacemakers and ICDs is only temporary, and normal function will resume as soon as the magnet is removed. Magnets can easily move out of a functioning position and do not provide a reliable or individualised modification of device programming. The advantage of magnet application is the simplicity and the lack of need to reprogramme the device after procedures (which avoids the possibility of failure to reprogramme ICD therapies back on). This approach is also practical at institutions which do not have cardiac physiology services on site.

For the purposes of these guidelines, a magnet refers to a specifically designed ring or block magnet, which should be available in all hospitals. Ring magnets should be positioned over the implantable device. It may be necessary to feel for the device as it may have migrated away from any visible implant scar. In addition, S-ICD generators are typically positioned beneath the axilla (rather than pre-pectoral).

The majority of manufacturers of the ICDs implanted in the UK (Medtronic, Minneapolis, MN, USA, Boston Scientific, Natick, MA, USA and Biotronik UK Ltd, Bicester, UK) advise positioning the magnet directly over the device. However, St Jude Medical/Abbott (Abbott; Chicago, IL, USA) recommends that the magnet is offset from the device with the curve of the ring magnet positioned over the top or bottom of the device (Fig. 2). LivaNova (LivaNova Plc, London, UK, formerly Sorin) advises that with its devices, the magnet should be positioned off-centre, avoiding the header at the top of the device. In the majority of clinical situations, a magnet placed directly over the ICD will be effective at withholding shock therapy. However, there are a number of important considerations. First, the use and function of the magnet must be fully understood and acknowledged. Second, the inhibition of shock delivery will

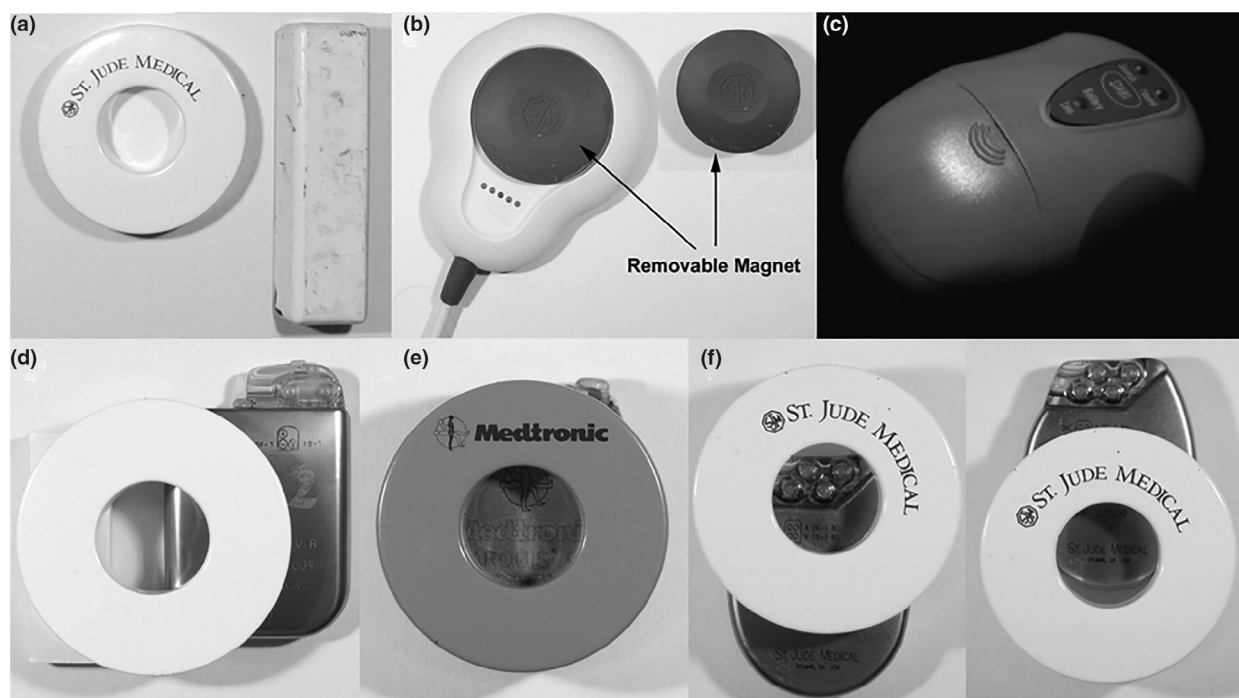


Figure 2 Clinical magnets and their proper placement as per manufacturer recommendations. (a) Ring/doughnut and bar magnets; (b) St. Jude Telemetry Wand magnet in position and removed from the wand; (c) Medtronic Smart Magnet™; (d) Sorin implantable cardioverter defibrillator: ring magnet placed off-centre avoiding the header on the top end of the device; (e) Medtronic, Boston Scientific and Biotronik implantable cardioverter defibrillators: ring magnet placed directly on top of the device; (f) St. Jude implantable cardioverter defibrillator: the curve of the ring/doughnut magnet on the top or bottom end of the device. Reproduced with permission from [25].

only be effective during correct magnet placement and that this should be secured to the patient for the duration of surgery using surgical tape. Magnets can easily shift position and need to be positioned correctly. If the surgical procedure is prolonged (> 8 h), Biotronik ICDs will revert to normal function, in which case the magnet needs to be removed and then reapplied. Third, any subsequent ventricular arrhythmia will need to be treated using external defibrillation equipment. Consider attaching any person whose ICD has been deactivated to an external defibrillator using hands-free pads. Finally, an ICD may emit an audible alarm/beep/vibration when close to a strong magnetic field or when a magnet is applied over the generator (online Supporting Information Appendix S1).

Pacemaker magnet response

Most pacemakers (simple and resynchronisation) respond with fixed-rate (asynchronous) pacing while a magnet is held over the generator. While this can be useful in rare situations where pacing is inhibited by diathermy, leaving a magnet over the pacemaker is not generally recommended. The asynchronous pacing can occasionally be

arrhythmogenic in patients with an underlying intrinsic cardiac rhythm (R-on-T phenomenon). Leadless pacemakers do not respond to magnets with fixed-rate pacing and therefore any programming changes need to be carried out using the specific device programmer. If this is not possible, particularly in a pacing-dependent person, caution is advised.

Response of ICDs to magnets

For ICDs, placing a magnet over the device will inhibit the delivery of anti-tachycardia pacing and shock therapy but will have no effect on bradycardia pacing. Clinical magnets for this application will be available from the local cardiac pacing centre along with instructions for correct use. Magnets should also be available from coronary care units and local guidelines should be in place to detail their locations.

These guidelines outline best practice for the peri-operative management of the increasing number of people with CIEDs. If people are appropriately identified pre-operatively, it should be possible to establish whether additional measures need to be taken to allow surgery to be

undertaken safely. Clear communication with the cardiac teams within each organisation is crucial to allow this to be undertaken effectively. People who are pacing-dependent and those with implantable defibrillators may require device reprogramming or magnet application during their procedure. The authors encourage centres to adapt these guidelines to their local infrastructure and resources.

Acknowledgements

No external funding or competing interests declared.

References

1. Thomas H, Turley A, Plummer C. British Heart Rhythm Society guidelines for the management of patients with cardiac implantable electronic devices around the time of surgery. 2016. <https://bhrrs.com/wp-content/uploads/2019/05/Revised-guideline-CIED-and-surgery-Feb-19.pdf> (accessed 17/03/2022).
2. Medicines and Healthcare products Regulatory Agency. Guidelines for the perioperative management of patients with implantable pacemakers or implantable cardioverter defibrillators, where the use of surgical diathermy/electrocautery is anticipated. 2006. [https://webarchive.nationalarchives.gov.uk/ukgwa/20100709170822/http://www.mhra.gov.uk/Safetyinformation/Generalsafetyinformationandadvice/Product-specificinformationandadvice/Cardiacpacemakersanddefibrillators\(implantable\)/Guidelinesforimplantablecardioverterdefibrillators-pacemakerperioperativemanagement/index.htm](https://webarchive.nationalarchives.gov.uk/ukgwa/20100709170822/http://www.mhra.gov.uk/Safetyinformation/Generalsafetyinformationandadvice/Product-specificinformationandadvice/Cardiacpacemakersanddefibrillators(implantable)/Guidelinesforimplantablecardioverterdefibrillators-pacemakerperioperativemanagement/index.htm) (accessed 17/03/2022).
3. Kristensen SD, Knuuti J, Saraste A, et al. 2014 ESC/ESA guidelines on non-cardiac surgery: cardiovascular assessment and management: the joint task force on non-cardiac surgery: cardiovascular assessment and management of the European Society of Cardiology (ESC) and the European Society of Anaesthesiology (ESA). *European Heart Journal* 2014; **35**: 2383–431.
4. Crossley GH, Poole JE, Rozner MA, et al. The Heart Rhythm Society (HRS)/American Society of Anesthesiologists (ASA) expert consensus statement on the perioperative management of patients with implantable defibrillators, pacemakers and arrhythmia monitors: facilities and patient management this document was developed as a joint project with the American Society of Anesthesiologists (ASA), and in collaboration with the American Heart Association (AHA), and the Society of Thoracic Surgeons (STS). *Heart Rhythm* 2011; **8**: 1114–54.
5. American Society of Anesthesiologists. Practice advisory for the perioperative management of patients with cardiac implantable electronic devices: pacemakers and implantable cardioverter-defibrillators 2020: an updated report by the American Society of Anesthesiologists Task Force on perioperative management of patients with cardiac implantable electronic devices. *Anesthesiology* 2020; **132**: 225–52.
6. Proietti R, Labos C, Davis M, et al. A systematic review and meta-analysis of the association between implantable cardioverter-defibrillator shocks and long-term mortality. *Canadian Journal of Cardiology* 2015; **31**: 270–7.
7. Indik JH, Gimbel JR, Abe H, et al. 2017 HRS expert consensus statement on magnetic resonance imaging and radiation exposure in patients with cardiovascular implantable electronic devices. *Heart Rhythm* 2017; **14**: e97–e153.
8. Zecchin M, Severgnini M, Fiorentino A, et al. Management of patients with cardiac implantable electronic devices (CIED) undergoing radiotherapy: a consensus document from Associazione Italiana Aritmologia e Cardioritmologia (AIAC), Associazione Italiana Radioterapia Oncologica (AIRO), Associazione Italiana Fisica Medica (AIFM). *International Journal of Cardiology* 2018; **255**: 175–83.
9. Korantzopoulos P, Letsas KP, Grekas G, Goudevenos JA. Pacemaker dependency after implantation of electrophysiological devices. *EP Europace* 2009; **11**: 1151–5.
10. Schulman PM, Treggiari MM, Yanez ND, et al. Electromagnetic interference with protocolized electrosurgery dispersive electrode positioning in patients with implantable cardioverter defibrillators. *Anesthesiology* 2019; **130**: 530–40.
11. American Society of Anesthesiologists. Practice advisory for the perioperative management of patients with cardiac implantable electronic devices: pacemakers and implantable cardioverter-defibrillators. An updated report by the American Society of Anesthesiologists Task Force on perioperative management of patients with cardiac implantable electronic devices. *Anesthesiology* 2011; **114**: 247–61.
12. Beinart R, Nazarian S. Effects of external electrical and magnetic fields on pacemakers and defibrillators: from engineering principles to clinical practice. *Circulation* 2013; **128**: 2799–809.
13. Gifford J, Larimer K, Thomas C, May P. ICD-ON registry for perioperative management of CIEDs: most require no change. *Pacing and Clinical Electrophysiology* 2017; **40**: 128–34.
14. Friedman H, Higgins JV, Ryan JD, et al. Predictors of intraoperative electrosurgery induced implantable cardioverter defibrillator (ICD) detection. *Journal of Interventional Cardiac Electrophysiology* 2017; **48**: 21–6.
15. Gifford J, Larimer K, Thomas C, et al. Randomized controlled trial of perioperative ICD management: magnet application versus reprogramming. *Pacing and Clinical Electrophysiology* 2014; **37**: 1219–24.
16. Ohira M, Silcox J, Haygood D, et al. Nerve conduction studies in patients with implanted devices are safe regardless of magnet placement. *Clinical Neurophysiology* 2012; **123**: e67–e68.
17. Cronin EM, Gray J, Abi-Saleh B, Wilkoff BL. Safety of repetitive nerve stimulation in patients with cardiac implantable electronic devices. *Muscle and Nerve* 2013; **47**: 840–4.
18. Zaphiratos V, Chiasson H, Drolet P, et al. Interference between surgical magnetic drapes and pacemakers: an observational study comparing commercially available devices and a new magnetically isolated drape. *Biomedical Engineering Online* 2016; **15**: 83.
19. Cadeddu J, Fernandez R, Desai M, et al. Novel magnetically guided intra-abdominal camera to facilitate laparoendoscopic single-site surgery: initial human experience. *Surgical Endoscopy* 2009; **23**: 1894–9.
20. Gotoda T, Oda I, Tamakawa K, Ueda H, et al. Prospective clinical trial of magnetic-anchor-guided endoscopic submucosal dissection for large early gastric cancer (with videos). *Gastrointestinal Endoscopy* 2009; **69**: 10–15.
21. Wolber T, Ryf S, Binggeli C, et al. Potential interference of small neodymium magnets with cardiac pacemakers and implantable cardioverter-defibrillators. *Heart Rhythm* 2007; **4**: 1–4.
22. Ladas SD, Triantafyllou K, Spada C, et al. ESGE clinical guidelines committee. European Society of Gastrointestinal Endoscopy (ESGE): recommendations (2009) on clinical use of video capsule endoscopy to investigate small-bowel, esophageal and colonic diseases. *Endoscopy* 2010; **42**: 220–7.
23. Tabet R, Nassani N, Karam B, et al. Pooled analysis of the efficacy and safety of video capsule endoscopy in patients with implantable cardiac devices. *Canadian Journal of Gastroenterology and Hepatology* 2019; **2019**: 3953807.

24. Healey JS, Merchant R, Simpson C, et al. Canadian cardiovascular society/Canadian Anesthesiologists' Society/Canadian Heart Rhythm Society joint position statement on the perioperative management of patients with implanted pacemakers, defibrillators, and neurostimulating devices. *Canadian Journal of Cardiology* 2012; **28**: 141–51.
25. Jacob S, Panaich SS, Maheshwari R, Haddad JW, Padanilam BJ, John SK. Clinical applications of magnets on cardiac rhythm management devices. *EP Europace* 2011; **13**: 1222–30.

Supporting Information

Additional supporting information may be found online via the journal website.

Appendix S1. Management of the WiSE-CRT system.

Appendix S2. Flow chart of the suggested peri-operative management of CIEDs.